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This report contains short descriptions of contractor efforts under the Ocean Engineering and Marine Systems Program at ONR during FY97. The descriptions are edited versions of year-end reports submitted by the Principal Investigators.

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ROBOTIC SYSTEMS

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LONG-TERM GOALS

Teleoperated platforms being introduced into the field are expected to assume a larger role in the access and neutralization of area denial and explosive devices. This work includes examination, identification, and disposal of ordnance. These manipulators that consist of a base platform and a multiple degree of freedom manipulator with end effector get carried to the work site by vehicles.

Current commercial and developmental arms are either too expensive for EOD use or do not have the flexibility and strength to weight ratio necessary for Render Safe Procedures (RSPs). Technologies that lead to serpentine manipulators and electrostrictive polymer actuators will be explored in this effort. Manipulators using these technologies would provide the operator, who is out of harms way, with high dexterity, which makes it valuable for complex and obstructed environments that are often encountered.

OBJECTIVES

The key to development of the manipulator is a new actuation technology that has been developed at SRI, an electrostrictive polymer artificial muscle. Muscle-like actuators based on this technology have the combination of high force-to-weight ratio, large stroke capability, good

speed of response, and high efficiency unavailable in other actuation technologies. The use of such actuators will allow for the development of an extremely lightweight and slender manipulator with a sufficient number of degrees of freedom to negotiate motion around obstacles. Manipulators using these actuators are expected to be inexpensive, efficient, and reliable. Our objective is to develop this technology to the point that a highly dextrose serpentine manipulator with a "follow the leader" control methodology can be realized for EOD access missions.

APPROACH

Several serpentine-like manipulators have been built in the past 20 years for terrestrial applications. All of them lack the positional accuracy, reach, and dexterity for EOD applications. Pacific Northwest National Laboratories (PNNL) performed a design study of a serpentine manipulator with an end effector in FY92. The design specifications were completed and the methodologies for development selected. Major technical issues confronted to date are: design and implementation of a "follow-the-leader" path for the end effector tip to snake around obstacles, the development and implementation of planning and control strategies for highly redundant serial link manipulators, and configuration and mechanical design of actuators and joints. However, the most challenging technical issue is the guidance of the arm in real time and in three dimensions by the remote EOD Technician. A portion of this work studies the interface between the EOD Technician and the manipulator.

The technology to bring about a "virtual reality" between the EOD Technician and "his" robotic arm are being explored in terms of video multiplexing two video images that were obtained from slightly different locations. The corresponding images are displayed to the operator's right and left eye in rapid succession. This 3-dimensional interactivity that requires attached video means to the end effector locality of the arm allows the remote operator interactive spatial arm control, simultaneous transitions, and rotations about the X, Y, and Z axes.

A breakthrough is needed to reduce the cost for a high strength, high dexterity, low cost manipulator. A promising technical approach to this problem is the use of electrostrictive polymers as actuators. Thin snake-like manipulators with a high number of degrees of freedom that would be capable of positioning an end-effector in a highly cluttered environment are not available. The main obstacle to their development has been the lack of lightweight and compact actuators capable of producing the needed forces (or torque), displacements, and speed of response. Many multiarticulated arm designs have placed the actuators on the manipulator base to avoid the issue of actuator size and mass.

One can readily see the advantage of muscle-like actuators by noting the many biological analogs to highly articulated dexterous manipulators that operate using muscular actuation. These biological manipulators include snakes, worms, caterpillars, centipedes and millipedes, eels, elephant trunks, octopus and squid tentacles, and prehensile tails of monkeys and other mammals.

SRI has been investigating electrostrictive polymers for several years. They are presently developing muscle-like actuators based on this technology for applications in small-pipe-inspection robots (< 2-cm diameter). In addition, an ongoing effort is developing electrostrictive polymer transducers for underwater sound generation.

In essence, a rubbery polymer is sandwiched between two compliant electrodes. When a voltage difference between the two electrodes is applied, the resulting electrostatic force compresses the thickness and expands the area of the polymer film. Both the compression in thickness and the expansion in length or width of the film can be used for actuation. The effective pressures that can be generated with electrostrictive muscle can be very large. Polyurethane, for example, has demonstrated pressures up to 1.9 MPa (285 psi). These values are much larger than those suggested by the breakdown voltages quoted in industrial literature. The key to achieving higher breakdown voltages is to use high-quality thin films, and eliminate any remaining electrical defects prior to operation.

As noted, the pressures produced in the actuation of the polymer muscle can be quite high in certain polymers. The resulting strains may also be quite large. Strains of over 10% have been produced in a variety of polymers with moduli of elasticity ranging from 0.4 to 17 MPa. Silicone rubber has produced the largest strains at over 30% in thickness. Note that while it is desirable to maximize the dielectric constant of the material, other factors, such as dielectric strength and uniformity of thickness of the film, may determine the magnitude of the electrostrictive response.

After a review of other technologies by SRI, not shown here, we conclude that electrostrictive polymer artificial muscle is an ideal actuator for snake-like manipulator as required by EOD applications.

WORK COMPLETED

A mockup serpentine arm was fabricated by PNNL during FY92. This mockup arm was motorized and manually operable by switches that operate individual joints without rate or position control, but at "sloth speeds." An evaluation of the mockup arm was performed at the NAVEODTECHDIV in the latter part of FY93. The NAVEODTECHDIV evaluation determined by simplified replicated field tasks that PNNL had fabricated the following: a practicable geometry for our needs; and the correct design range of speeds for the arm to perform our work. These initial tests in FY93 showed that the prototype arm should be modeled after the mockup arm. The prototype now has the same basic geometry as the mockup, but more degrees of freedom (14), greater degree-of-motion in the joints of the arm, and sufficient joint torque for manipulation at the end effector extremity of the arm for the following rendering safe tools: voltage and current measurement probes, wire cutters, stereoscopic video means, and shields for denial devices.

The design of the prototype joints was subjected to a basic stress analysis in FY94 of critical components during operational loading. Further, a vibration analysis was included to identify any fundamental resonant frequencies associated with the overall length and moment of inertia of the prototype. For example, electric prime movers on the arm that operate at a rotation rate

coincident with a fundamental natural frequency of the prototype arm may induce unwanted motion at the free end of the arm.

The serpentine arm test bed was demonstrated at PNNL during the second quarter of FY97 to examine the following: control algorithms and computer codes developed for control of the serpentine arm; the concept of "virtual reality" guidance of the arm by the user; and the feasibility/patency of the sophisticated follow-the-leader serpentine arm entry and withdrawal. It was determined that the task goals of the task had been met. The arm was crated and shipped to NAVEODTECHDIV for further experimental testing. Unfortunately, the hard drive for the serpentine arm was found to be defective when the arm was reassembled at NAVEODTECH-DIV. The hard drive has been sent back to the manufacturer for repair under warranty. Experimental results are expected in FY98.

SRI started work on the electrostrictive polymer muscle task, a 6.2 effort, on 1 May 1996 with a literature search and review of work performed by technologists in this field. Dr. Bar-Cohen of JPL, who is presently engaged in research in electrostrictive polymer artificial muscle, provided a lecture for SRI investigators during November 1996 to exchange data.

Work at SRI has involved analysis and modeling of the electrostrictive polymer phenomenon. Because materials with higher permittivity (dielectric constants) develop greater effective pressure from electrostatic squeezing and stretching, SRI has synthesized polymer films with lanthanum fluoride, liquid crystal polymer, inorganic salts, barium titanate, lanthanum fluoride, lead and magnesium nobate, and other dopants to obtain materials with higher permittivity.

RESULTS

Related new technologies to the field of artificial muscle have been assessed. Polypyrrole polymer, a material that undergoes dimensional changes when undergoing redox reactions, was investigated. However, the redox reactions in this material were judged too slow and inefficient for the needs of this task. New piezoelectric actuator types, RAINBOW and THUNDER, were reviewed for possible application to this task. Also, ultrasonic motors based on resonating disks of piezoelectric ceramics and mechanical gels as a basis of artificial muscle actuators were examined.

Further, Dr. Nitzan performed a Technology Definition Study on rendering-safe procedures for IEDs. This study serves to define the path that SRI's development of polymer muscle should follow. A path that will lead to practicable tools for RSPs. Presently, SRI is in the process of fabricating proof-of-principle actuators that may serve as prime movers for such tools.

IMPACT/APPLICATIONS

There is a specialized need for an arm that can move precisely inside of an object without contacting any surfaces. Arm control must be precise, slow, and deliberate. The inadvertent bumping, or even touching, of the arm into bomb components, electronics, or structure may have disastrous results. Therefore, the EOD technician must be able to spatially determine the exact

location of the arm during an RSP. Further, the arm must operate at a slow or "sloth speed." A computer will keep track of where the arm has been and, therefore, where it may not deviate to when it is withdrawn.

If developed, use of an artificial muscle, electrostrictive materials, would have a vast array of applications that would serve as prime movers for: "sloth" type serpentine arms; inexpensive bomb disablement and UXO retrieval robots; and artificial prostheses.

TRANSITIONS

The completed serpentine arm transitioned this fiscal year to the Defense Technical Response Group (DTRG) for further experimental testing.

This technology will transition to both conventional EOD Joint Service programs and for specialized mission groups that support the Army's 52nd Ordnance Group.

The technology for polymer muscles will be transitioned to ongoing Advanced Development programs to enhance manipulator performance and reduce cost.

RELATED PROJECTS

Teleoperated systems, Standard EOD robot (SEOD) and the Remote Controlled Transporter (RCT), have been fielded for limited use by EOD Technicians. These limits are partially due to the limited dexterity and strength of the manipulator

The Jet Propulsion Laboratory's (JPL's) Rover and Telerobotics Program, sponsored by the National Aeronautics and Space Administration (NASA) has a research program that is dedicated to the development of actuation technology based on electrostrictive polymer (ESP) materials and actuation mechanisms are being developed in the form of "muscles."

Virginia Polytechnic Institute has a project to develop a movable truss for NASA-Langley. This work is under review for application to this effort. DARPA and the Army have designed and/or built serpentine manipulators. They will not meet the environmental requirements of EOD, but the technologies are useful.

REFERENCES

1. SRI International Quarterly Report, "Dexterous Multiarticulated Manipulator with Electrostrictive Polymer Artificial Muscle," ITAD-7247-QR-96-175, SRI Project Number 7247, November 1996.
2. Jesse Allan Willett, "A Highly Dexterous Serpentine Robotic Manipulator," American Nuclear Society Seventh Topical Meeting on Robotics and Remote Systems, April 27 - May 1, 1997.